



Transport
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TP 3522

M. V. Arctic Data Collection and Instrumentation 1980 Season

Summary Report

Prepared for the
Transportation
Development Centre
Transport Canada

August 1981

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FENCO

1311-9th Ave. S.W.
3rd Floor
Calgary, Alberta T3C 0H9
403-237-6466
Cable 'FENCOENG'
Telex 03-821373

September 24, 1982

Mr. H. Brenckmann
Associate Director
Transport Canada
Transportation Development Centre
1000 Sherbrooke Street West
MONTREAL, Quebec
H3A 2R3

Transport Canada / Transports Canada
Library and Information Centre /
Centre de Documentation GSLA
Ottawa, Canada K1A 0N5

Dear Mr. Brenckmann,

M.V. ARCTIC DATA COLLECTION AND INSTRUMENTATION
1980 SEASON

Please find enclosed seventy-five (75) copies of the final summary report on M.V. Arctic Data Collection and Instrumentation 1980 - Season.

We hope that this final version of the report meets with your approval.

Yours very truly,
FENCO CONSULTANTS LTD.

K. K. Vij.

K. K. Vij
SENIOR SCIENTIST

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M.V. ARCTIC
DATA COLLECTION AND INSTRUMENTATION
1980 SEASON

SUMMARY REPORT

BY
FENCO CONSULTANTS LTD.
AND
GERMAN + MILNE INC.

PREPARED BY
V.W. NETH AND D.H. BOTELER

AUGUST 1981

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre.

PROJECT TEAM

The project team for FENCO CONSULTANTS LTD. was composed of:

Dr. V. Weth

Mr. D. Boteler

Dr. B. Narod

Mr. W. Graham

The project team for German + Milne Inc. was composed of:

Mr. G. German

Mr. J. Carter

Mr. A. Benjamin

Mr. J. Stirling

REPORT DOCUMENTATION FORM

1. Transport Canada Report No. TP 3522	2. TDC Project No. 4127	3. Recipient's Catalogue No.
4. Title and Subtitle M.V. "Arctic" Data Collection and Instrumentation, 1980 season. Summary Report	5. Report Date August 1981	6. Performing Organization Report No.
7. Author(s) V.W. Neth, D.H. Boteler	8. Transport Canada File No. D1460-166-13	
9. Performing Organization Name and Address FENCO CONSULTANTS LTD. 3rd Floor 1311-9th Avenue S.W. Calgary, Alberta T3C 0H9	10. DSS File No. 09SD.T8200-9-9546	11. DSS or Transport Canada Contract No. 0SD80-00010
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 1000 Sherbrooke Street West, P.O. Box 549 Montreal, Quebec H3A 2R3	13. Type of Report and Period Covered Summary June - November 1980	14. Sponsoring Agency Code
15. Supplementary Notes	16. TDC Project Officer D. Hearnshaw	
17. Abstract This is a summary report of data collection and analysis activities aboard M.V. "Arctic" during the 1980 northern shipping season. Data was collected from some 200 sensors. The majority of the sensors are comprised of about 100 strain gauges and are permanently fixed to the ship's hull. The remaining sensors record data related to ship performance and machinery parameters. Prior to the commencement of any data collection activities, the entire system was evaluated and calibrated to ensure that the data acquired is reliable. With the aid of the system, data was collected and partly analyzed during four voyages while the ship was on its normal operations. Data was also acquired during the dedicated ship trials north of Baffin Island. Prior to the start of the data collection season, specific sampling rates were assigned to each sensor, whilst keeping in mind the reduced sampling capability of the system. Sampling rates and response data were investigated, including such features as rise times and sensitivity of gauges to impact location on hull frames and plates. Durations and effects of collisions with various types of ice were recorded and analyzed. A limited amount of strain gauge data was analyzed statistically for different ice, broadly grouped as multi-year, first year and pressure ridge ice. Among the conclusions offered is that 30 cm ice did not produce significant strains in the ship's hull, even at speeds of 6.2 m/sec, and that the distribution of strain magnitudes is independent of the duration of the recording period.		
18. Key Words Instrumentation, Data Collection, Ice Breaking, Arctic Vessels, Ship Performance, Navigation	19. Distribution Statement Limited number of copies available from TDC.	
20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages 27
		23. Price

FORMULE DE DOCUMENTATION POUR RAPPORT

1 N° du rapport Transports Canada TP 3522		2 N° de l'étude — CDT 4127		3 N° de catalogue du destinataire	
4 Titre et sous-titre M.V. "Arctic" Data Collection and Instrumentation 1980 Season Summary Report				5 Date du rapport août 1981	
				6 N° du rapport de l'organisme exécutant	
7 Auteur(s) V.W. Neth, D.H. Boteler				8 N° de dossier Transports Canada D1460-166-13	
9 Nom et adresse de l'organisme exécutant FENCO CONSULTANTS LTD. 1311, 9th Avenue S.W. 3rd floor Calgary, Alberta T3C 0H9				10 N° de dossier — ASC 09SD.T8200-9-9546	
				11 N° de contrat — ASC ou Transports Canada OSD80-00010	
12 Nom et adresse de l'organisme parrain Centre de développement des transports (CDT) 1000 ouest, rue Sherbrooke Montréal (Québec) H3A 2R3				13 Genre de rapport et période visée Rapport sommaire juin - novembre 1980	
				14 Code de l'organisme parrain	
15 Remarques additionnelles				16 Agent de projet — CDT D. Hearnshaw	
17 Résumé Ce résumé porte sur la saisie et l'analyse de données effectuées à bord de l'Arctic durant la saison de navigation arctique de 1980. Ce système comporte quelque 200 détecteurs, une centaine environ sont des jauges de contrainte fixées à demeure à la coque, les autres étant affectés à l'enregistrement de données relatives au comportement du navire et des machines. Avant de commencer le programme de saisie des données, le système a été évalué et étalonné afin d'assurer la fiabilité des données recueillies. Le volume I traite de la saisie des données et de leur dépouillement partiel durant les quatre voyages réguliers du navire, alors que le volume II traite des opérations effectuées durant les essais spécialisés, au nord de l'île de Baffin. Avant que ne débute la série d'essais, la fréquence d'échantillonnages de chacun des détecteurs avait été déterminée, compte tenu de la capacité réduite d'échantillonnages du système dans son ensemble. La fréquence et les caractéristiques de la réponse instrumentale ont aussi été étudiées, notamment les temps de montée et la sensibilité des jauges aux impacts selon qu'elles touchaient les tôles ou les membrures de la coque. Les impacts sur les divers types de glaces ont été enregistrés et analysés quant à la durée et à l'intensité. Un dépouillement statistique a été fait des données tirées d'un certain nombre de jauges sur les impacts avec des glaces diverses d'après leur appartenance aux trois grands types retenus: glaces de plusieurs années, de première année et crêtes de pression. Ces essais ont montré entre autres, que des glaces de 30 cm ne produisent que peu d'effet sur la coque, même à la vitesse de 6,2 m/s, et qu'il n'existe pas de corrélation entre la distribution des amplitudes d'impacts et la durée d'enregistrement.					
18 Mots-clés Instrumentation, Saisie de données, Brise-glace, Navires de classe arctique, Comportement de navire, Navigation			19 Diffusion Disponibilité d'exemplaires en nombre limité au CDT		
20 Classification de sécurité (de ce rapport) Aucune		21 Classification de sécurité (de cette page) Aucune		23 Prix Aucun	
				22 Nombre de pages 27	

ACKNOWLEDGEMENTS

The project team gratefully acknowledges the co-operation and assistance provided by the officers and crew of the M.V. Arctic.

During our time on the ship, the captains and officers on the bridge were very helpful in explaining ice conditions and showed considerable interest in the data collected. The chief engineer and the engine room personnel provided invaluable assistance with the calibration of the propulsion sensors and in installing a new shaft RPM sensor. Crew members were also helpful with outside work on the ship.

FOREWORD

The M.V. Arctic, an Arctic Class II 28,000 dwt bulk carrier, was built in 1978 and is the first ship designed to comply with the Canadian Arctic Shipping Pollution Prevention Regulations (CASPPR). At the suggestion of the Transportation Development Centre (TDC) the M.V. Arctic was equipped with a data acquisition system for recording the performance of the ship in ice. This system was installed by German + Milne Inc. and operated by them during the 1979 arctic shipping season, and during brief ship trials in the Saguenay River in January 1980. For the 1980 arctic shipping season the system was operated by FENCO CONSULTANTS LTD., in association with German + Milne Inc., during the regular shipping operations and during ship trials at the north of Baffin Island.

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1. INTRODUCTION

The M.V. Arctic is a 28,000 ton deadweight icebreaking bulk carrier designed to meet the Class II requirements of the Canadian Arctic Shipping Pollution Prevention Regulations (see Table 1.1 for M.V. Arctic - ship characteristics). During the arctic summer, the M.V. Arctic usually makes a series of voyages from Nanisivik Mine on the northern end of Baffin Island to Antwerp, Belgium, often having to break ice on the arctic section of the journey.

Prior to the 1980 season, an extensive overhaul of the data acquisition system was performed and all sensors calibrated. Sampling schemes were devised considering the limitations of the system and the expected frequency content of the measured parameters. During the regular voyages, recordings were made whenever the ship was in ice and a preliminary analysis of the data was made on board the ship. A detailed statistical analysis was made subsequently using a large high-speed computer ashore. A full description of this work, the recordings made, and the results obtained are given in Volume I of the final report "Data Collection and Instrumentation, 1980 Season."

In October 1980, the M.V. Arctic was chartered by the Transportation Development Centre for a series of dedicated trials off the north of Baffin Island. Tests were made of the speed/power performance (turning circle and manoeuvrability) of the ship in sheet ice from 19.5 cm to 35.5 cm thick. On board measurements were made of the ship speed, engine performance and hull response to the ice, while ice teams measured the thickness, characteristics and strength of the ice. All the data collected was analysed and the results are presented in Volume II of the final report "Data Collection and Instrumentation, 1980 Season".

1.1 Regular Voyages

Three trips were originally planned for the 1980 arctic shipping season but later a fourth trip was added following the dedicated trials north of Baffin Island (see Fig. 1.1 to 1.4). A total of 21 magnetic tapes were recorded in conditions ranging from open water (force 10 winds), to thin first-year sheet ice, to multi-year ice floes. Conditions which produced measurable ice impacts are shown in Table 1.2 together with the tapes recorded in each case that were selected for further analysis. A more detailed record of the ice conditions prevailing is available on video tape.

1.2 Baffin Island Trials

The trials team assembled on Thursday, October 23, at Pond Inlet on the northern end of Baffin Island to await the arrival of the M.V. Arctic. An ice reconnaissance flight was made on October 24 and the ship arrived on October 25. The trials were conducted from October 26 to 31, during which time 41 tests were performed as the ship moved from Pond Inlet to Nanisivik (Figure 1.5). Most of the trials team left the ship at Nanisivik on November 1, however, several trials personnel remained on board while the ship retraced its route to Pond Inlet, arriving there on November 2.

TABLE 1.1

M.V. ARCTIC - SHIP CHARACTERISTICS

Length Overall	209.55 m
Length Between Perpendiculars	196.60 m
Moulded Draught	22.86 m
Moulded Depth	15.24 m
Moulded Breadth	10.97 m
Summer Draught	10.82 m
Block Coefficient	0.753
Prismatic Coefficient	0.761
Light Ship	9,276.1 t
Displacement at 10.81 m draught	37,724.1 t
Dead Weight at 10.81 m draught	28,448.0 t
Cargo Capacity	36,490.8 cubic metres
Propulsion Machinery - MAN Diesel	11,014 kilowatts
Generators	900 kw x 3
Complement	40
Speed on Trials	15.5 knots
Cruising Range	14,000 nautical miles

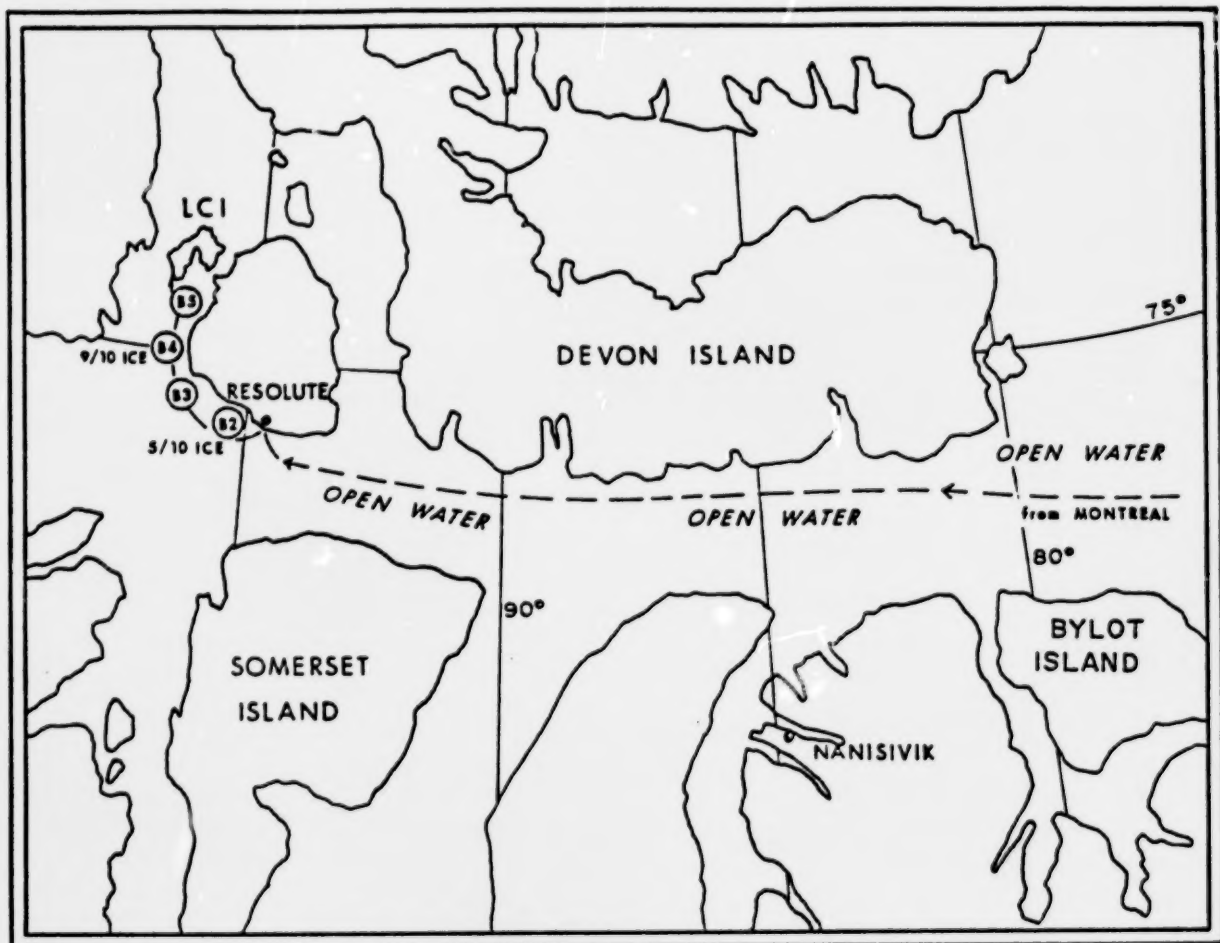


FIGURE 1.1 SHIP'S ROUTE ON TRIP #1
(Number in circles indicate magnetic tape numbers)

Trip #1

The ship departed Montreal on August 10 for its first trip and followed the route shown in Figure 1.1 arriving at Little Cornwallis Island (L.C.I.) on August 17. Ice was only encountered between Resolute Bay and L.C.I. and during this time the ship was following a C.C.G. icebreaker so there were no major impacts. However, one test tape and four data tapes were recorded for comparison with analogue recordings made at the same time.

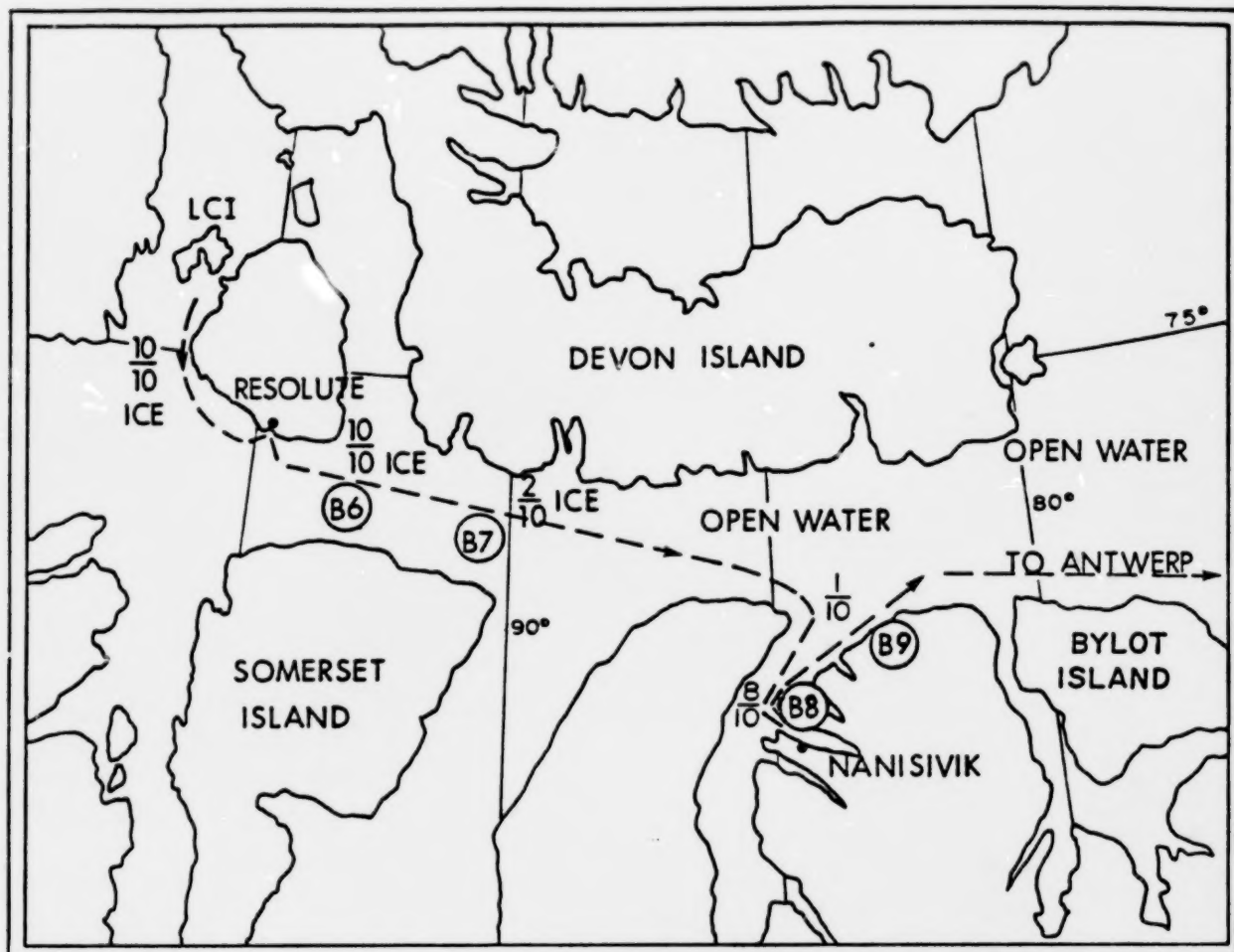


FIGURE 1.2 SHIP'S ROUTE ON TRIP #2
(Number in circles indicate magnetic tape numbers)

Trip #2

Departing L.C.I. on September 3, the ship went to Resolute and Nanisivik and then across to Antwerp, returning to Nanisivik on September 30. Heavy ice was passed through between L.C.I. and Resolute but no recordings were made because the data acquisition system was not ready for use and the laboratory space was being used for other purposes. More ice was encountered between Resolute and Nanisivik, as well as on leaving Nanisivik, and two tapes were recorded on each occasion (Figure 1.2). On the return journey there was 3 cm new ice in Admiralty Inlet but with the ship in ballast most strain gauges were above the waterline so no recordings were made.

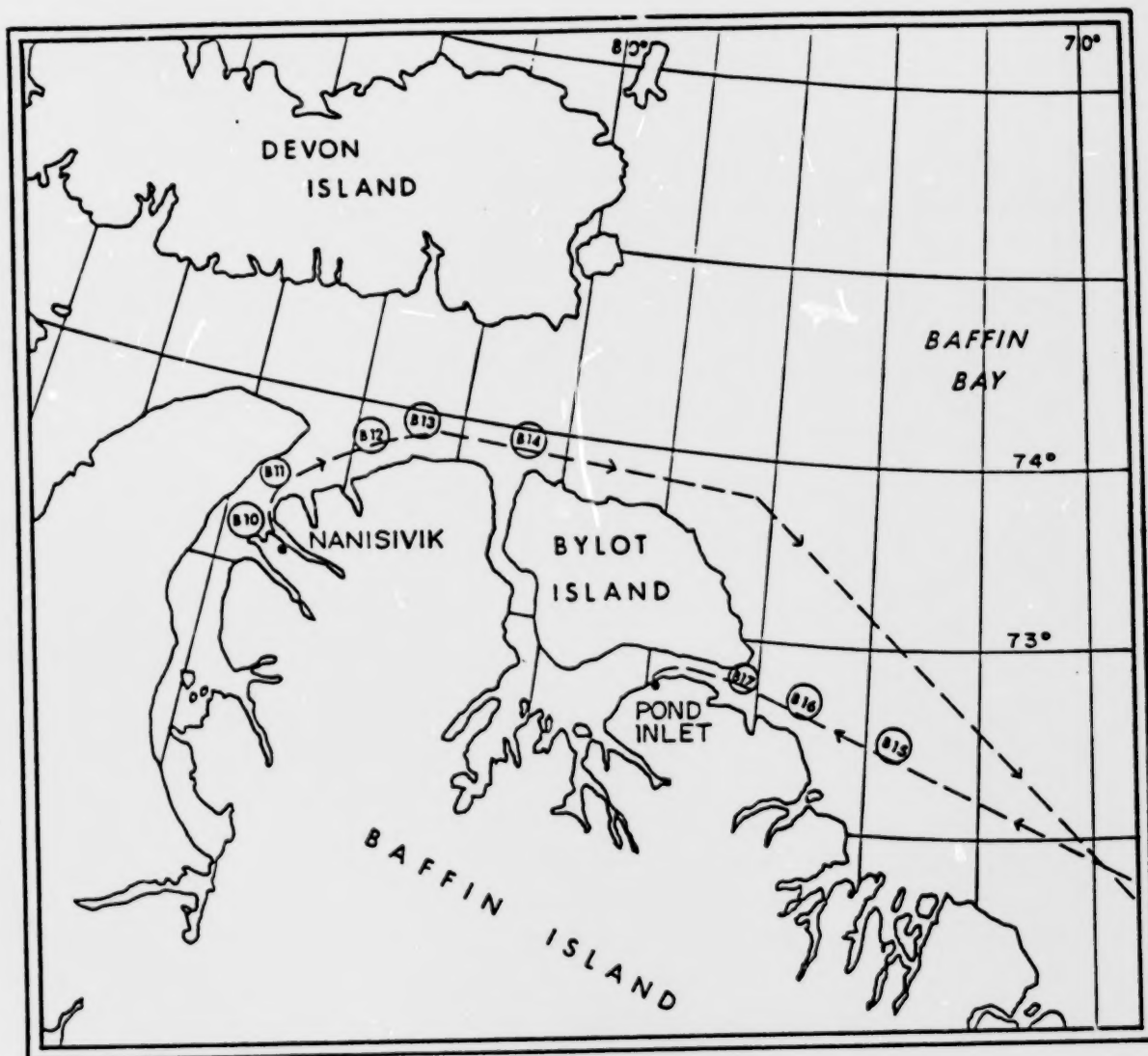


FIGURE 1.3 SHIP'S ROUTE ON TRIP #3
(Number in circles indicate magnetic tape numbers)

Trip #3

On departure from Nanisivik on October 3, the ship was now down to its loaded waterline and five tapes were recorded enroute to Antwerp (Figure 1.3). In late October three tapes were recorded approaching Pond Inlet where the ship arrived on October 25.

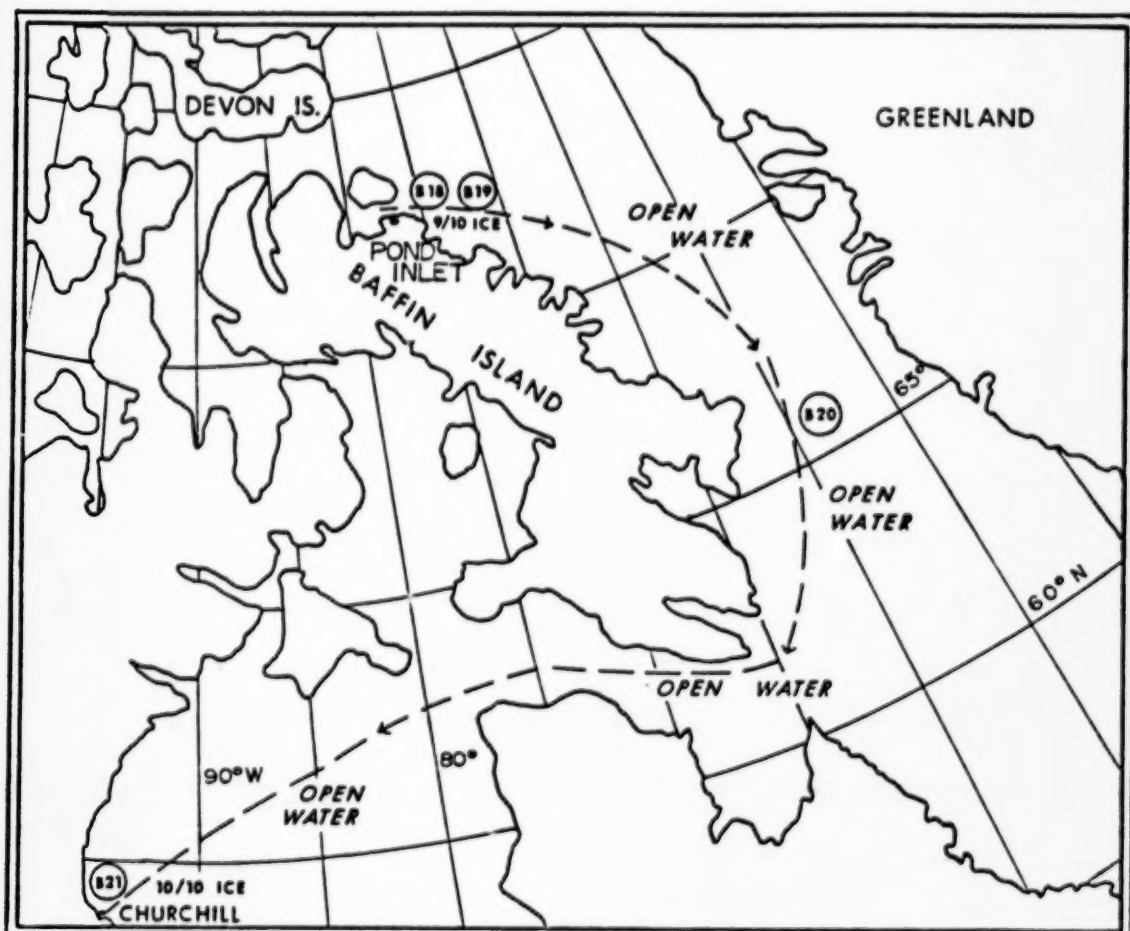


FIGURE 1.4 SHIP'S ROUTE ON TRIP #4
(Number in circles indicate magnetic tape numbers)

Trip #4

Leaving Pond Inlet on November 2, the ship passed through heavy multi-year ice where two tapes were recorded (Figure 1.4). Further out into Baffin Bay the ship entered open water and one tape was recorded here during conditions of force 10 winds. Open water prevailed until close to Churchill where northeasterly winds had caused an accumulation of first-year ice, and one tape was recorded on the way into Churchill and while the ship was manoeuvring at the dock.

TABLE 1.2

ICE CONDITIONS ENCOUNTERED IN 1980 ARCTIC SHIPPING SEASON
AND TAPES SELECTED FOR DETAILED ANALYSIS IN EACH CASE

ICE TYPE	THICKNESS	MONTH	TAPE
Multi-Year	3 m	September	B8 - B9
Multi-Year	3 m	October	B13 - B14
Multi-Year	2 m	November	B18 - B19
First-Year Pack	600 - 900 mm	September	B6 - B7
New Open Pack	150 - 300 mm	October	B15
New Consol. Pack	300 mm	October	B16
New Consol. Pack	300 mm	November	B21

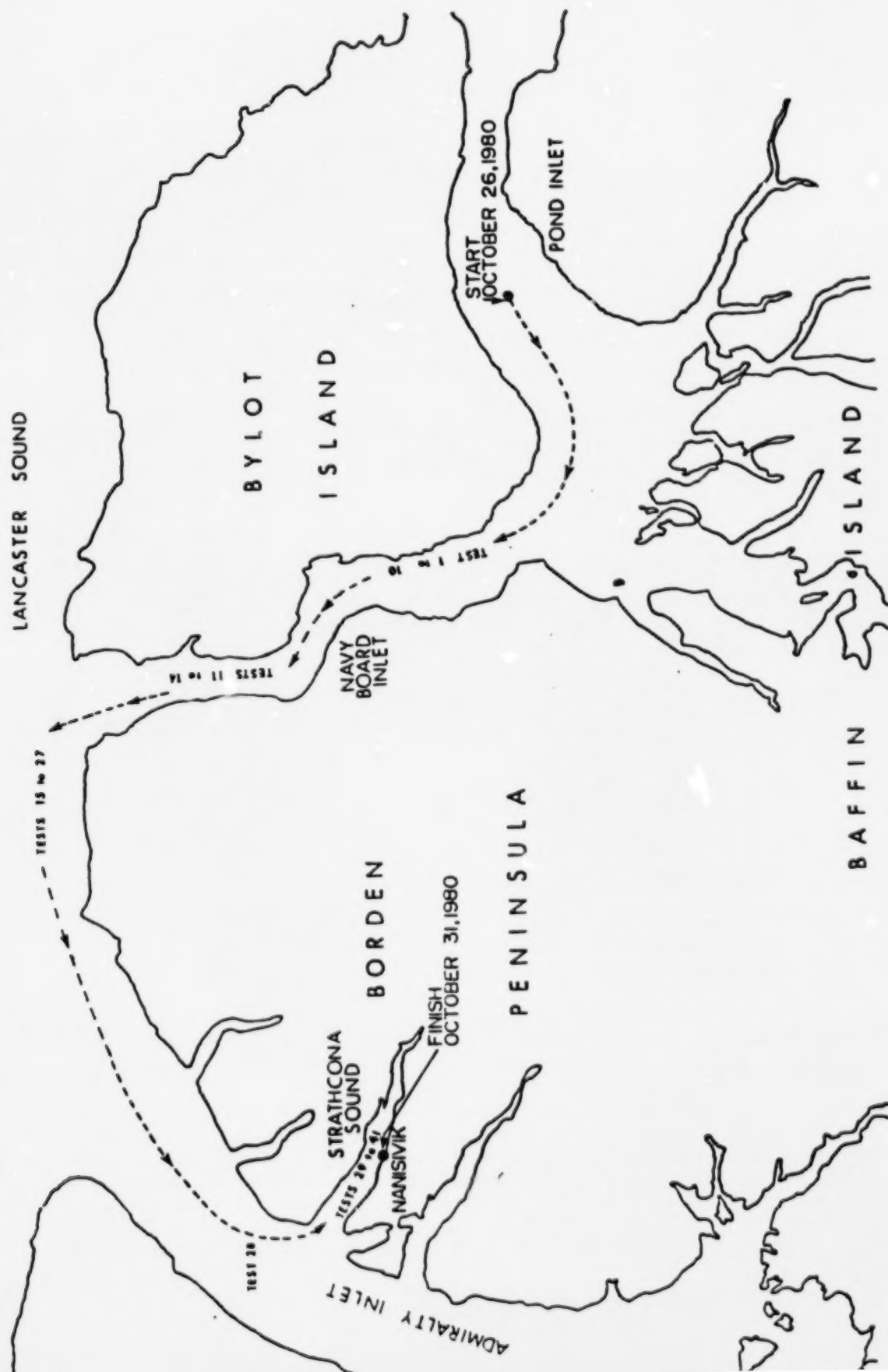


FIGURE 1.5 SHIP'S ROUTE DURING BAFFIN ISLAND TRIALS

2. MEASUREMENTS

During the regular voyages, one person operated the data acquisition system and noted the ice conditions. For the trials, as well as continuous recording with the data acquisition system, extra personnel monitored the ship's performance while an ice team measured the ice properties.

2.1 Data Acquisition System

Before the start of the 1980 arctic shipping season, a major examination and overhaul of the system was conducted. The results of this examination were detailed in an Evaluation Report submitted to TDC but most of the recommendations made in that report have now been implemented. Normally system changes and repairs would be noted in an equipment log, however, because of the extent of the changes and the lack of any circuit descriptions, it was thought preferable to organize all the information into a new equipment manual. Subsequently, a software manual was written and discussion of setting-up procedures and suggested sampling schemes were added. This information is contained in the System Operation and User's Manual, Volumes I, II, and III, May 1981, TP 3097, available from TDC.

The range of parameters collected by the data acquisition system is given in Table 2.1.

The system uses time-division multiplexing which involves briefly measuring each parameter in turn and recording each 'sample' on tape. This puts the measurements in a form suitable for computer processing and as long as the sampling rate is fast enough, an accurate reproduction of the original parameter can be obtained from the recorded data. Precautions, though, have to be taken against the effects of aliasing whereby fast variations (i.e., frequency components above the Nyquist frequency) in measured parameters can constitute 'noise' in the recorded data. To avoid this problem, low pass filters have been added to the system for recording selected strain gauges at 100 samples/second. Recording all gauges at this sampling rate, however, is not possible because of the maximum system sampling rate of 1765 samples/second, and is not desirable because of the unnecessary detail (and volume) of the data recorded. With each sensor, though, there is a peak-holding circuit which enables recordings to be made of the peak values that occur in each interval between samples. Thus the system has the flexibility to record data in a variety of detail depending on the requirements of the user. For example, the strain gauges are all recorded in 'peak' mode to provide data for determining impact loading and distribution, and selected strain gauges are additionally recorded, through filters, at high sampling rates to provide information on the dynamic response to impacts.

2.2 Ship Trials

Speed/power tests were carried out to determine the power requirements to transit through 20-30 cm thick level ice. Measurements were made of the shaft torque and RPM and the turboblower RPM from

TABLE 2.1:

PARAMETERS MEASURED BY THE M.V. ARCTIC DATA ACQUISITION SYSTEM

1. Hull Structure:	Plate Strains
	Frame Strains
2. Ship Performance:	Ship Speed
	Ship's Heading
	Pitch and Roll
	Accelerations, Fwd. and Aft.
3. Propulsion and Steering:	Shaft Torque
	Shaft RPM
	Shaft Thrust
	Fuel Rack Setting
	Propellor Command/Response
	Rudder Command/Response
	Rudder Differential Pressure
4. Environmental:	Wind Speed
	Wind Direction

which values for the shaft horsepower could be derived. Speed was measured manually by timing the ship past markers on the ice and these values compared with the doppler log readings. The speed attained at different power levels was measured with and without the bubbler system in operation.

Turning circle tests were performed with and without the bubbler, and at full and half power. In each case, the ship's track was traced from the true-motion display on the radar.

A number of general manoeuvring tests were carried out including breakout tests, backing in broken channels, acceleration, Kempf and "star" manoeuvres. A full list of all tests conducted are given in Table 2.2.

2.3 Ice Testing

Ice thickness was measured at regular intervals along the ship's track and in each test area measurements were made of ice properties. The ice survey team used a number of standard test procedures to determine ice characteristics. From core samples, vertical temperature and salinity profiles were recorded. Thin sections cut from these cores provided grain size and crystal orientation data.

In situ and laboratory tests were done to determine the following mechanical ice properties:

Confined Compressive Strength : FENCO Borehole Jack Test
and Modulus of Elasticity (in situ)

Unconfined Compressive Strength: FENCO Flaking Test
(in situ)
Uniaxial Test
(Laboratory)

Flexural Strength and : Cantilever Beam Test (in situ)
Strain Modulus

A summary of the measured mechanical ice properties is given in the following:

2.3.1 First year ice

- unconfined compressive strength (in situ) = 8.5 MPa
- unconfined compressive strength (laboratory) = 12.6 MPa
- flexural strength = 335 KPa
- strain modulus = 950 MPa

2.3.2 Multi-year ice

- confined compressive strength = 18.5 MPa
- modulus of elasticity = 1850 MPa

The Division of Building Research, National Research Council of Canada contributed to the ice testing.

TABLE 2.2
TRIALS INDEX

<u>TEST NO.</u>	<u>DATE</u>	<u>LOCATION</u>	<u>TEST</u>
1	26/10/80	NBI(1)	Speed/Power
2	26/10/80	NBI(1)	Turning Circle
3	26/10/80	NBI(1)	Speed/Power
4	27/10/80	NBI(1)	Breakout
5	27/10/80	NBI(1)	Acceleration Astern
6	27/10/80	NBI(2)	Speed/Power
7	27/10/80	NBI(2)	Backing
8	27/10/80	NBI(2)	Track Breakout
9	27/10/80	NBI(3)	Speed/Power (Bubbler)
10	27/10/80	NBI(3)	Speed/Power
11	28/10/80	NBI(4)	Kempf Manoeuvre
12	28/10/80	NBI(5)	Breakout
13	28/10/80	NBI(6)	Power/Check
14	28/10/80	NBI(6)	Speed/Power
15	28/10/80	LS(1)	Speed/Power
16	28/10/80	LS(1)	Acceleration
17	28/10/80	LS(1)	Turning Circle
18	28/10/80	LS(1)	Speed/Power
19	28/10/80	LS(1)	Turning Circle
20	29/10/80	LS(2)	Breakout
21	29/10/80	LS(2)	Backing
22	29/10/80	LS(2)	Speed/Power (Bubbler)
23	29/10/80	LS(2)	Speed/Power
24	29/10/80	LS(2)	Speed/Power (Bubbler)
25	29/10/80	LS(2)	Speed/Power
26	29/10/80	LS(2)	Backing
27	29/10/80	LS(3)	Speed/Power
28	30/10/80	AI(1)	Ice Impact
29	30/10/80	AI(2)	Star Manoeuvre
30	31/10/80	STR(1)	Speed/Power
31	31/10/80	STR(1)	Speed/Power
32	31/10/80	STR(1)	Speed/Power
33	31/10/80	STR(1)	Speed/Power
34	31/10/80	STR(1)	Speed/Power
35	31/10/80	STR(1)	Speed/Power
36	31/10/80	STR(1)	Star Manoeuvre
37	31/10/80	STR(2)	Docking
38	31/10/80	STR(3)	Turning Circle
39	31/10/80	STR(3)	Turning Circle
40	31/10/80	STR(3)	Turning Circle
41	31/10/80	STR(3)	Turning Circle

Abbreviations:

NBI = Navy Board Inlet
LS = Lancaster Sound
AI = Admiralty Inlet
STR = Strathcona Sound

3. RESULTS

3.1 Ice-Hull Interaction

Recordings were made in a variety of ice conditions during the 1980 arctic shipping season. Plate and frame strains were normally recorded at a rate of 1 sample/second, peak in order to determine the location and magnitude of ice impacts. As shown in Fig. 3.1 no significant strains were recorded by gauges above stringer 5 or below stringer 4; i.e. almost all impacts occurred between 0 and 2.5 metres below the waterline.

3.1.1 Statistical Result

A limited amount of statistical analysis was done on a number of tapes. Histograms produced for tape B6, recorded in unconsolidated pack ice on September 4, 1980 (Figure 3.2), shows the number of impacts that produced strains of 150-300 μS , 300-450 μS , and >450 μS . These histograms show an expected inverse relationship between the number and magnitude of impact strains. The detailed statistical investigation of strains showed the same general pattern but exposed differences between the response of the single skin and double skin regions and differences due to different ice conditions. Analysis of a short and long period of data produced basically the same results. However, high strains, which are the ones of interest, occur comparatively infrequently, and so long periods of data have to be analyzed to accurately determine their occurrence rates.

3.1.2 Dynamic Characteristics

Due to the limitations of the data acquisition system only a few plate and frame gauges were recorded at a rate of 100 samples/second in order to study the dynamic ice-hull interaction. Impacts with multi-year floes showed impact times of 0.15 second and 0.30 seconds for plate and frame gauges, respectively. From the limited amount of data recorded it appears that the type of ice encountered has little effect on the impact duration. The strain gauge data showed that the hull plate responds faster to an impact than the frames. Also, plate gauges show a negative strain after the main impact due to rebound of the plate. The associated rise times for plates and frames were about 0.07 seconds and 0.12 seconds, respectively.

3.1.3 Ice Load Calculations

Determining ice loads from strain gauge data involves complex methods of structural analysis. Complex, because the curvature of frames and the hull plate is not known. Knowing the curvature, stresses or strains of a beam on a plate can easily be found by applying straight forward structural analytical methods.

As a first step the strain data collected aboard the M.V. Arctic should be screened with the objective to analyse a few selected "events". Ideally, the analysis should be done in two parts; namely

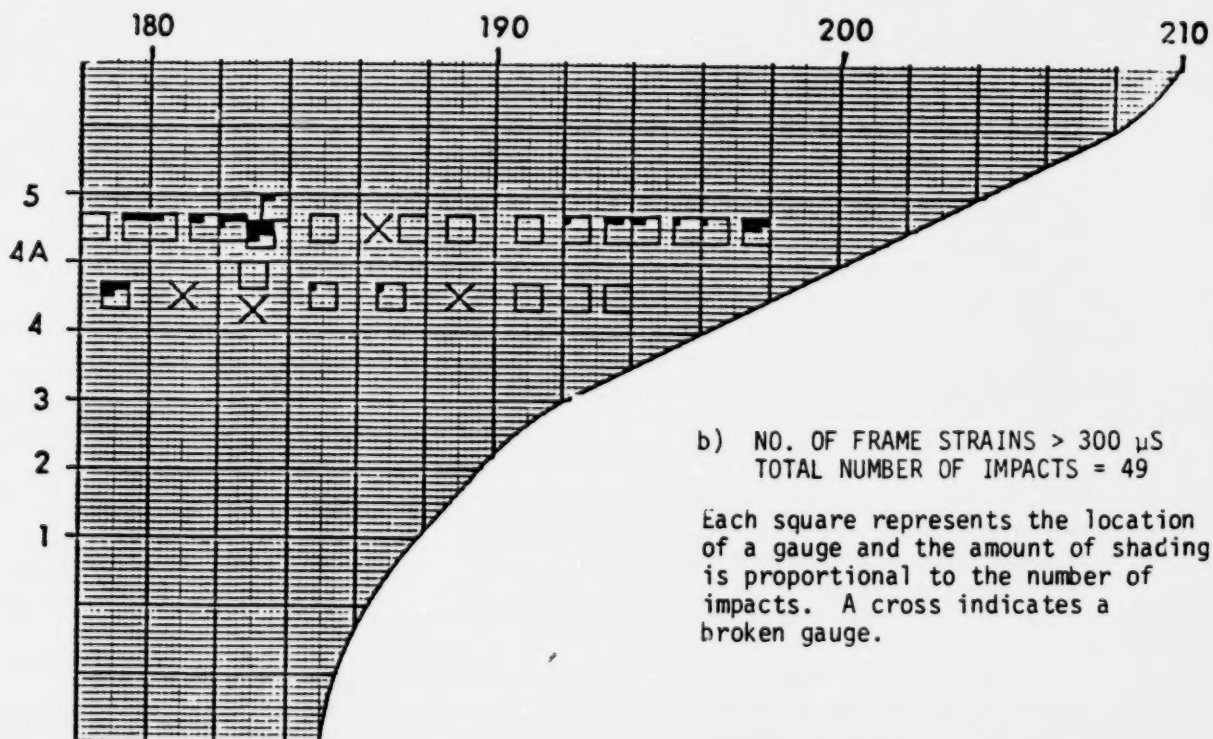
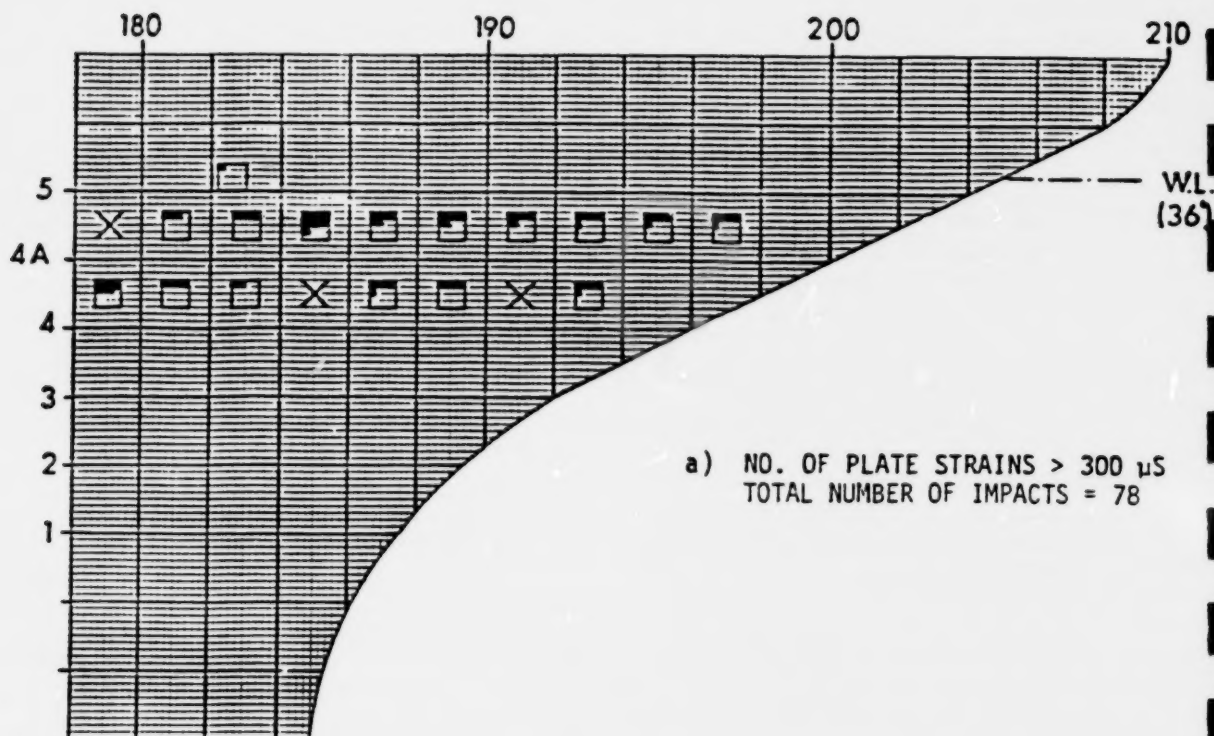


FIGURE 3.1 PLATE AND FRAME STRAINS RECORDED IN UNCONSOLIDATED PACK ICE ON SEPTEMBER 4, 1980 FOR A PERIOD OF 1.5 HOURS

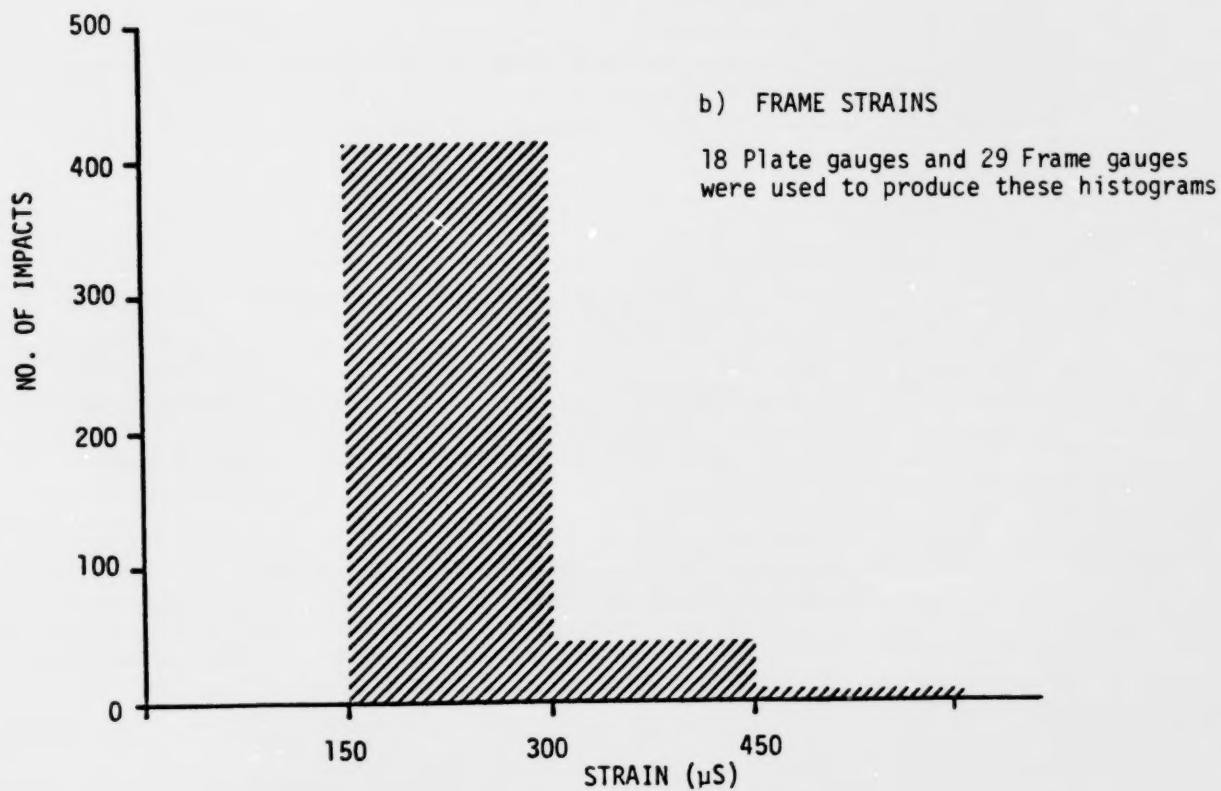
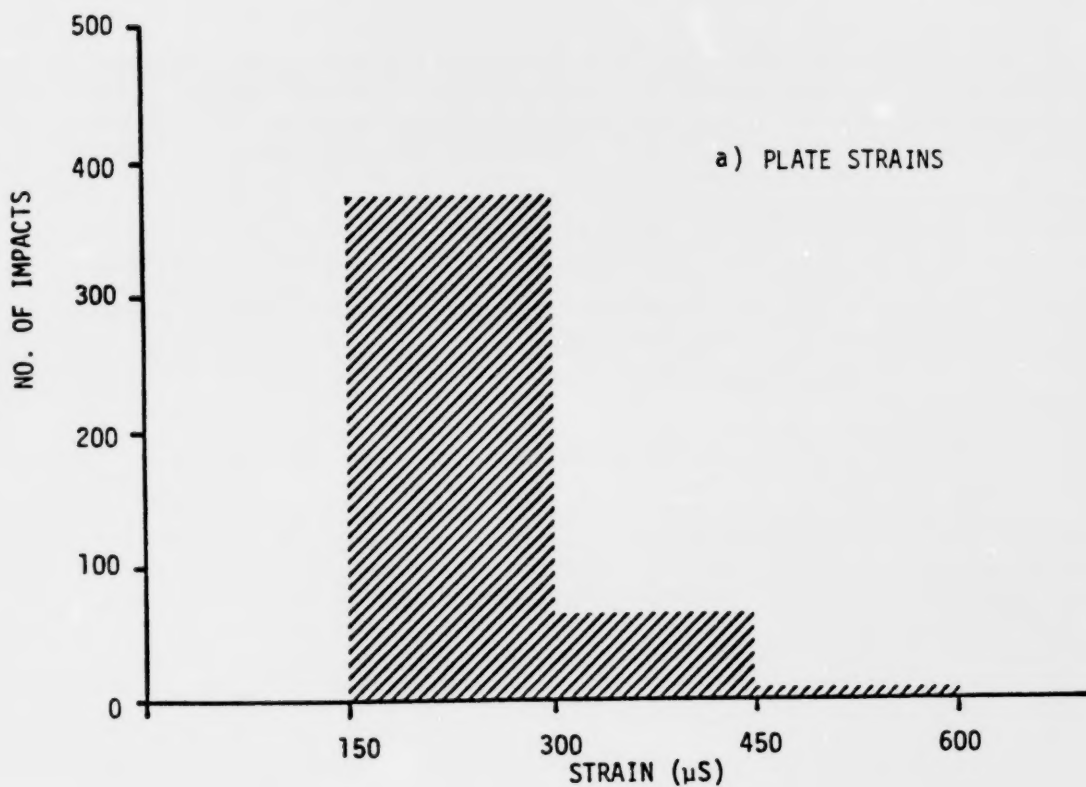


FIGURE 3.2 HISTOGRAMS FOR PLATE AND FRAME STRAINS
RECORDED ON SEPTEMBER 4, 1980

determining firstly ice loads from particular strain gauge patterns, and secondly, to use the calculated loads in a finite element model which in turn will determine the resulting strain values. The accuracy of the ice load calculation can then be judged by comparing strain patterns. In going through several events it should be possible to develop a methodology which in turn leads to the development of computer software which can be used to handle a large number of ice load reductions from strain gauge data. In the following, only two ice impacts will be studied with the aim to demonstrate that there is a sound analytical approach which can eventually be used when employing computers.

Case Histories

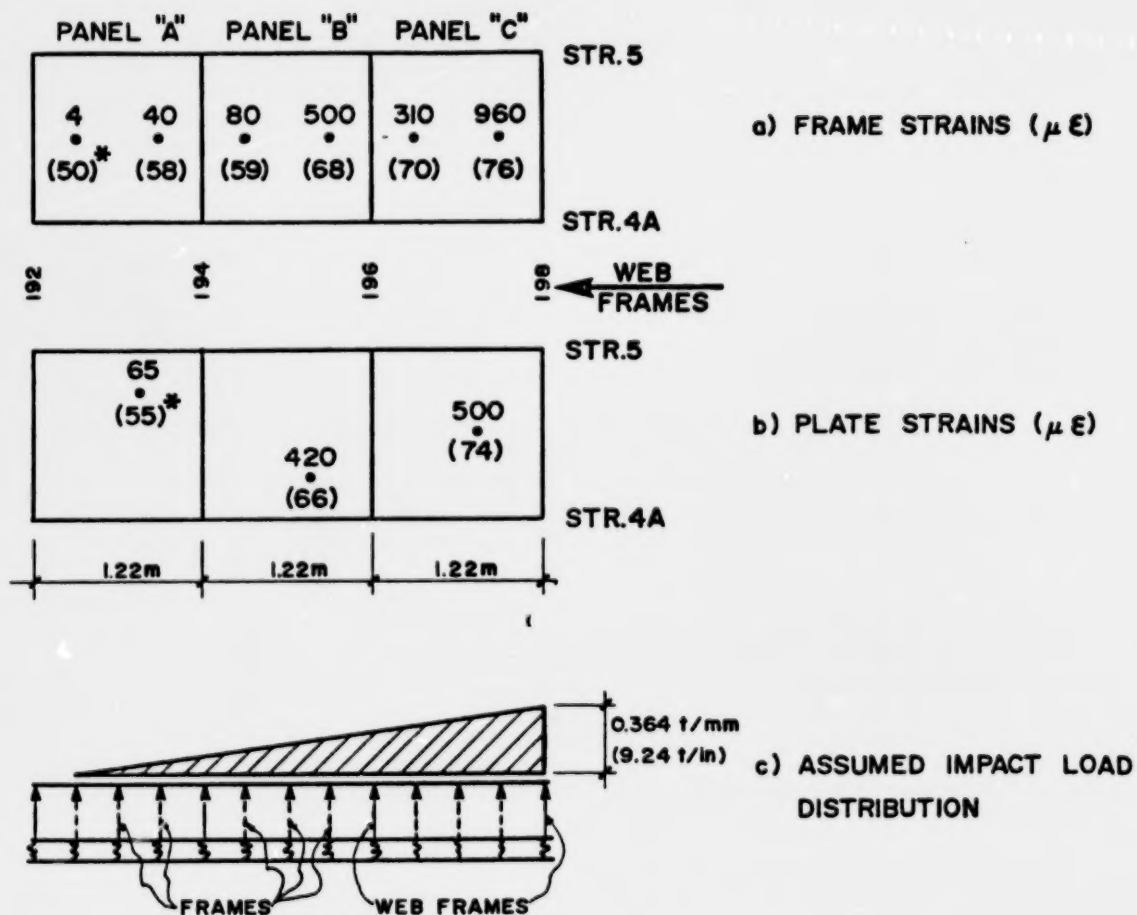
Two major ice impacts were recorded when the ship contacted a multi-year ice floe. On September 8, 1980, at 01.24 GMT, the ship hit a multi-year floe, several hundred metres across and approximately 3 m thick. The ship was travelling at about 7 knots but was brought to a halt by the impact. Two impacts occurred simultaneously, approximately 10 metres apart, at 33 seconds after the minute. The first impact occurred 1.0 to 1.5 m below the waterline involving three panels between frames 192 and 198 (single skin structure). The second impact was recorded about 2.0 m below the water line between frame 180 and 182, an area which has a double skin structure.

The hull structure with the strain gauges attached to it is used as a load transducer. A transducer has to be calibrated; which was done at the starboard side with the aid of a hydraulic ram and a loading beam in 1978. One of the main objectives of the calibration tests was to establish so-called sensitivity coefficients which form the link between the external load and the corresponding strain gauge readings. The coefficients depend on the structural configuration and the loading characteristics. The sensitivity coefficients used in the following examples are 1.8 and 3.0 $\mu\text{S/ton}$ for the outer skin and the frames, respectively.

The first impact involves three panels as shown in Fig. 3.3. First, each panel will be considered separately and then an assessment will be made whether the impact involves all three panels simultaneously or each panel is affected by a separate impact. The frame and plate strains are given in Fig. 3.3a and b, respectively. A first inspection indicates that the frame as well as the plate strains decrease with decreasing frame members. Based on the sensitivity coefficients given above and the strains shown in Fig. 3.3a and b the load range for each panel is given as follows:

Panel A	15 - 35t
Panel B	170 - 235t
Panel C	280 - 320t

The total average load for all panels amounts to 530t. If one assumes that all three loads act simultaneously, a load configuration shown in Fig. 3.3c can be assumed.



* NUMBER IN BRACKETS () INDICATES STRAIN GAUGE CHANNELS

FIGURE 3.3 STRAINS AND ICE LOAD FROM IMPACT
ON SEPTEMBER 8, 1980 AT 01:24:33

In case of the second impact, the ice load can only be determined from a plate gauge reading which indicated a value of 1540 μ S (see Fig. 3.4). Using a sensitivity value of 1.8 μ S/ton, the impact load can be estimated as 850 t which at first sight appears to be high. It should be noted, however, that the recorded plate strain of 1540 μ S exceeded the yield strain by nearly 40% which resulted in a permanent deformation of the outer skin. Assuming a confined compressive strength of 30 MPa - which is a common value for multi-year ice - the load was distributed over an area of approximately 500 mm square.

Recordings were made of the tri-axial accelerations of the bow and stern and the strains in mid-section longitudinal beams beneath the deck. These records show a sinusoidal variation in the vertical acceleration (heave), forward and aft, in phase with a sinusoidal variation in the mid-section longitudinal strains.

The amplitude of variation in acceleration, measured as 1.6 ft./sec.² (0.05 g), is given by $(2\pi f)^2 A$, where f in this case is 0.9 Hz. Thus, A , the range of vertical movement of the bow and stern, can be calculated and was found to be 0.5 in.

The above equations show that a sinusoidal variation in displacement of frequency, f , produces a sinusoidal variation in acceleration with the same frequency but 180° out of phase. Thus an upward (positive) acceleration is produced when the bow (or stern) is displaced downwards.

Extension in the longitudinal beams above the neutral axis (positive strain) coincide with upward (positive) accelerations of the bow and stern which is consistent with the 2-node vertical mode of hull vibration.

3.2 Ship Performance

The power/speed performance during the tests without the bubblers activated is shown in Figure 3.5. A general relationship between ice thickness and power requirements can be noted, although the curve for 30.7 cm mean thickness is higher than those for 32.9 and 35.6 cm. This anomaly may be explained by the fact that the ice field in the area of the test was under some pressure as it was noted that the channel was often closing after the passage of the ship. The other curves appear to show relatively good correlation.

Figure 3.6 depicts the relationship of power versus velocity in plate ice with and without bubbler activated. This figure shows that for the same value of SHP, the ship speed does increase with the bubbler system 'ON'. The results of this comparison were obtained from the data gathered on the same day and in the same ice field, but due to the variation in the thickness of ice sheet and with only a limited number of data points with the bubbler activated, it is rather difficult to draw a definite conclusion, regarding the effect the bubbler system has in this instance.

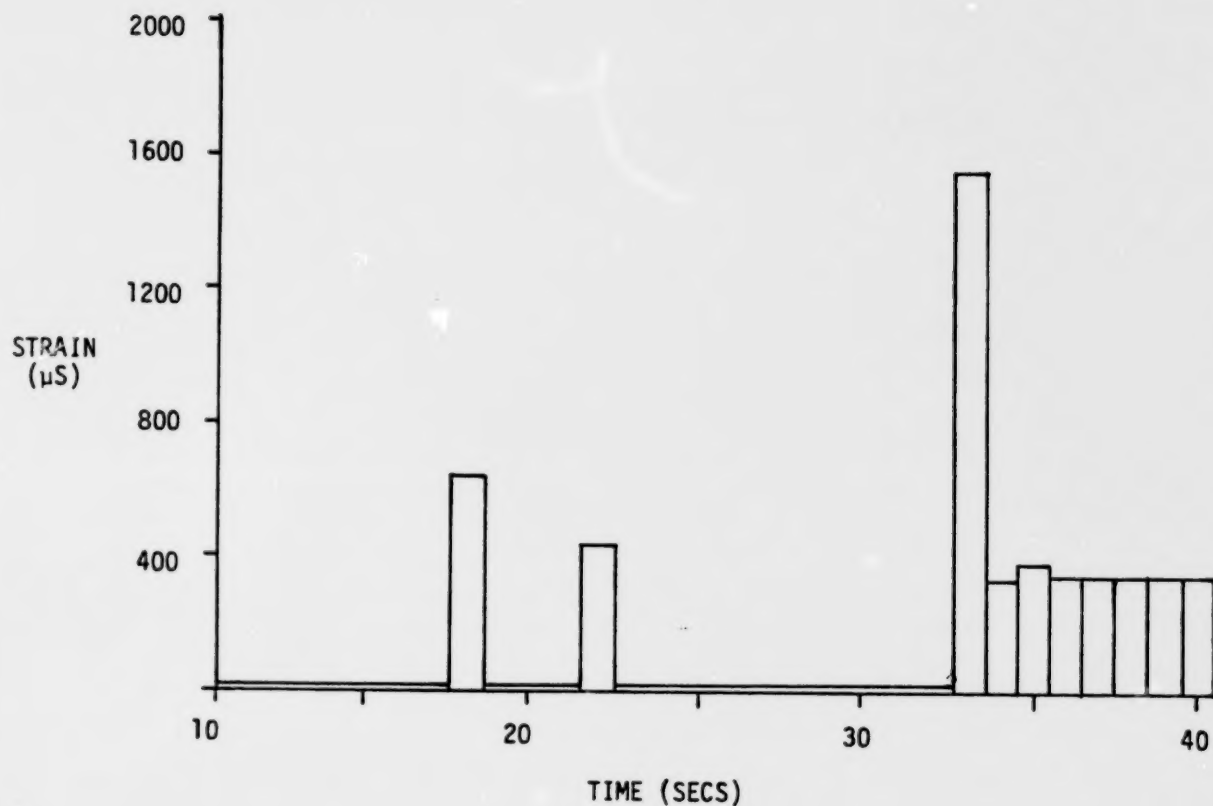


FIGURE 3.4 LARGE ELASTIC AND PLASTIC STRAINS RECORDED BY PLATE SG #126
(Caused by ice impact of multi-year ice floe at 01.24 GMT,
September 8, 1980)

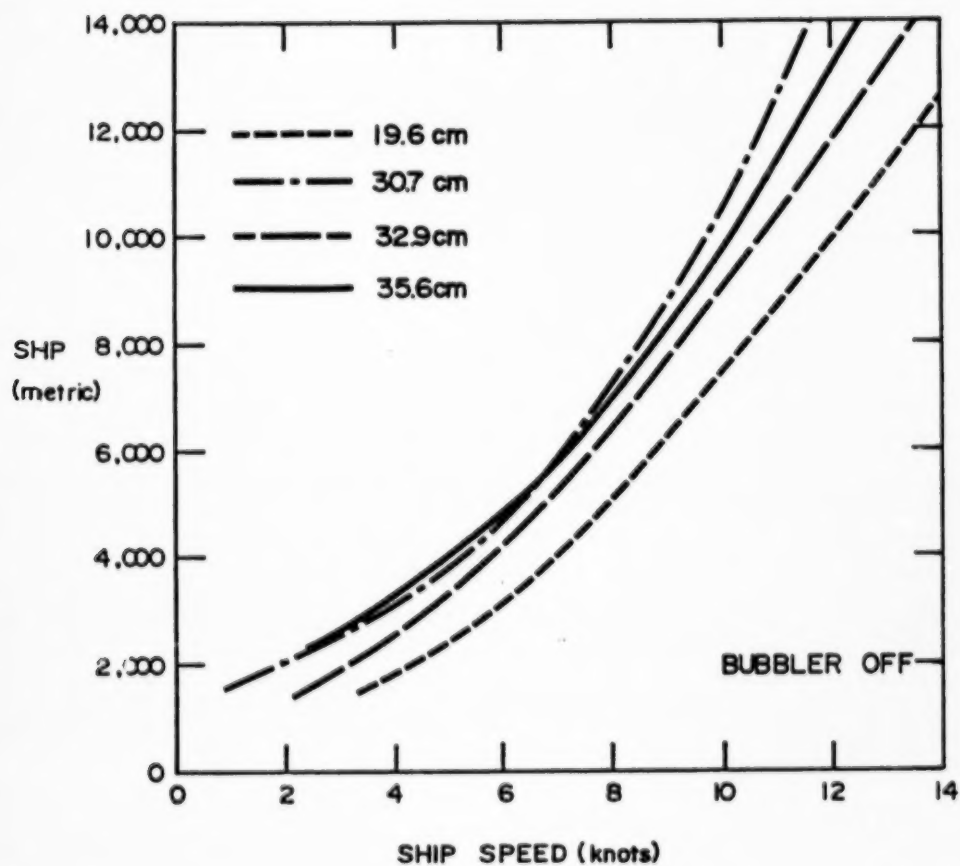


FIGURE 3.5 POWER/SPEED PLOTS FOR THE M.V. ARCTIC IN VARIOUS ICE THICKNESSES

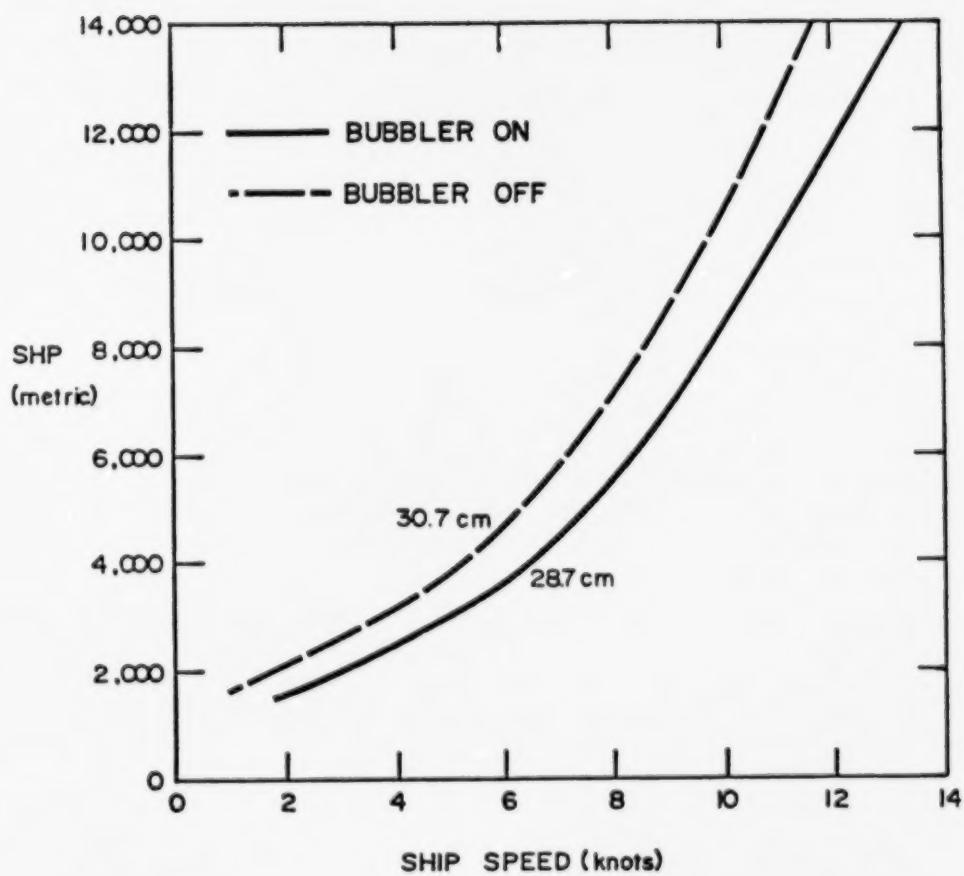


Fig. 3.6 Power/Speed Plots for the M.V. Arctic in level ice, with and without the bubbler.

Figure 3.7 depicts the relationship of power versus velocity in plate ice (mean thickness 33.0 cm) with and without the bubblers activated. Note that in this case speeds below 2.48 knots were not recorded and although the bubbler system may show advantages below this speed, it does not seem to have any effect above a speed of 2.48 knots in the ice conditions encountered.

Ice measurements in the test areas showed mean temperatures from -3.1°C to -5.0°C and salinities from 5.8 o/oo to 7.1 o/oo. The flaking tests gave a mean unconfined compressive strength value of 8.5 MPa while the cantilever beam tests gave flexural strengths of 235 kPa to 410 kPa.

Turning circle tests were performed at full power in 33 cm level ice. The turning circle diameter with the bubbler activated was 1.42 nautical miles compared with 1.70 nautical miles without the bubbler activated.

Figures 3.8a and 3.8b indicate the turning circles for the vessel again in 33 cm ice with and without the bubblers activated but at a reduced power level. Figure 3.7a shows the plot without the bubbler activated and in this case the turning circle diameter is approximately 1.25 nautical miles. With the bubblers activated the turning circle diameter reduces quite dramatically, as indicated in Figure 3.7b, to 0.55 nautical miles.

In all cases as the vessel transited from the second to third quadrant radial cracking occurred back to the track. This action tended to be delayed well into the third quadrant where bubblers were not activated and midway in the second quadrant where the bubbler system was operating. The radial cracking explains the rather hooked end to all the turning circle tests as the ice outside the circle tended to remain intact and hence "push" the bow around sharply.

"Star" manoeuvres were carried out to determine the ability of the vessel to reverse the bow direction in the minimum diameter by backing and filling, and the time to carry out such a manoeuvre. The first test, carried out in Admiralty Inlet, was performed in ice of average thickness of 13 cm and was accomplished in a circle diameter of 0.23 nautical miles, the elapsed time being 30 minutes. The second test took place in Strathcona Sound in ice of average thickness of 32 cm. In this instance, the manoeuvring space covered an oval area of 0.32 X 0.50 nautical miles and the time elapsed for the manoeuvre was 45 minutes.

A Kempf manoeuvre was performed in 30 cm ice to measure the time taken for the vessel to respond to rudder settings of 20° port, then 20° starboard. Travelling at a mean speed of 10 knots the vessel took 1 minute 27 seconds to come 20° to port, travelling 0.24 miles in the process, and then 3 minutes 25 seconds to go 20° to starboard of its original heading, travelling a further 0.6 miles.

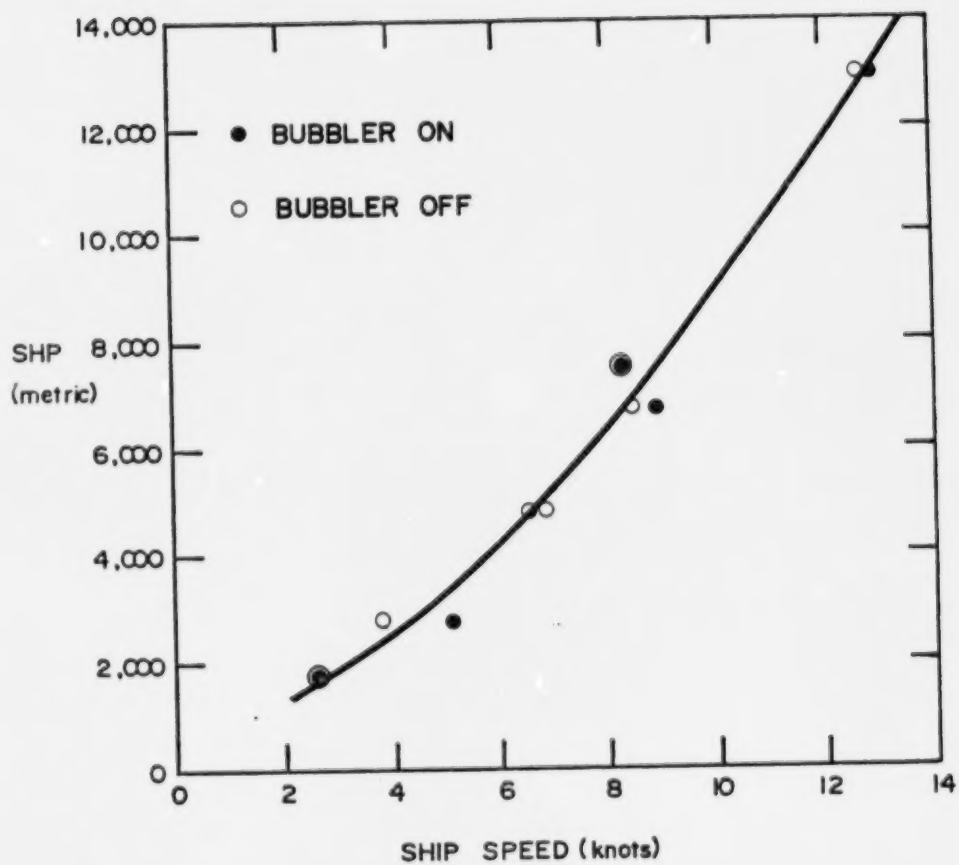


FIGURE 3.7 POWER/SPEED PLOT FOR THE M.V. ARCTIC IN
LEVEL ICE OF 33 cm MEAN THICKNESS

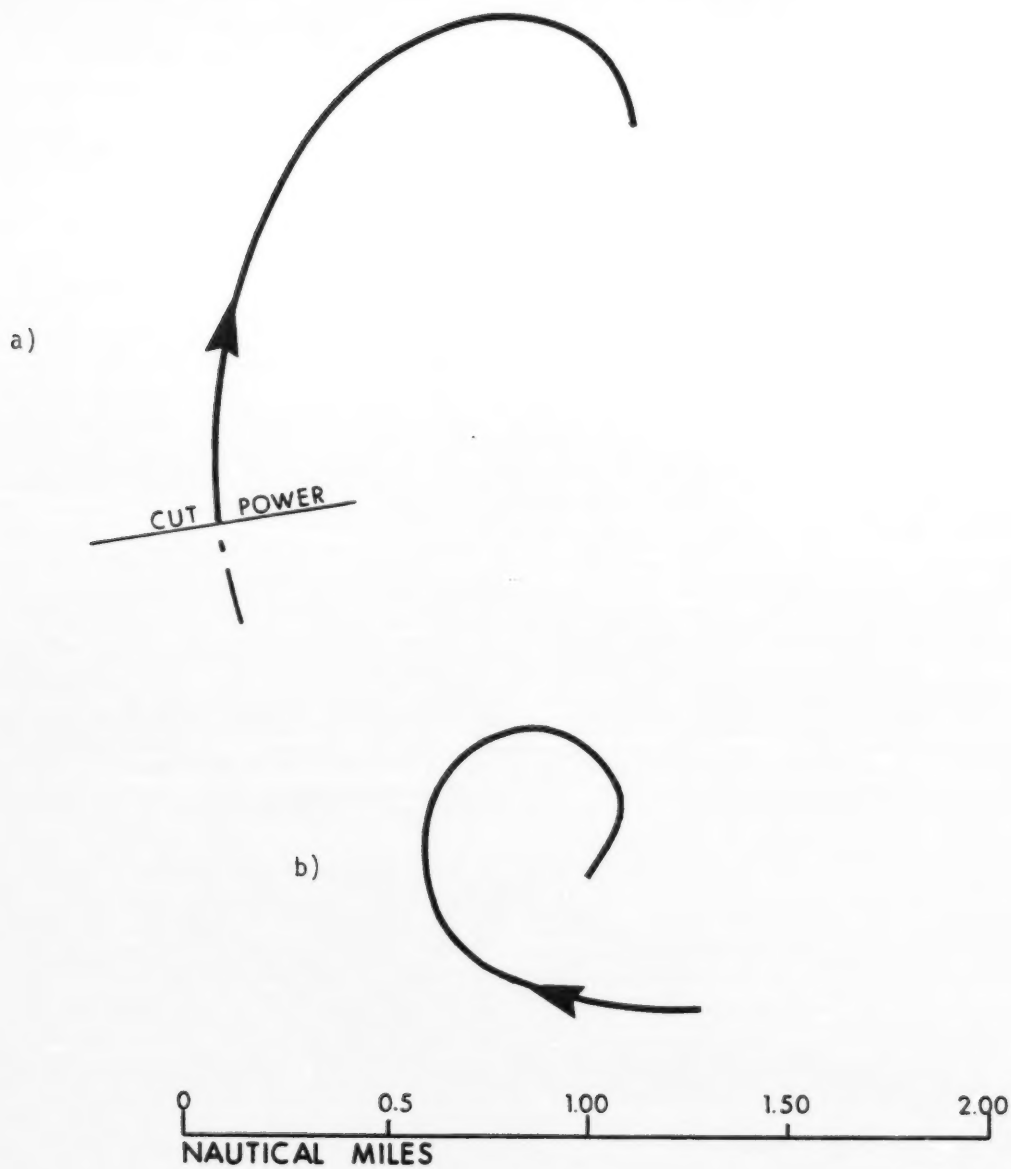


FIGURE 3.8 TURNING CIRCLES OF THE M.V. ARCTIC IN 33 cm ICE
a) WITHOUT BUBBLER, SHP = 8000 (METRIC)
b) WITH BUBBLER, SHP = 8000 (METRIC)

4. CONCLUSIONS

1. Accurate measurements of the speed performance of the M.V. Arctic have been obtained in sheet ice from 19.5 cm to 35.5 cm thick.
 - 1.1 At full power a speed of 13.5 knots was achieved in 20 cm ice.
 - 1.2 At full power a speed of 10 knots was achieved in 30 cm ice.
 - 1.3 Due to limited number of data points it is difficult to draw any definite conclusions regarding the effect the bubbler system has on the ship speed for the ice conditions encountered. Figure 3.6 shows that for the same value of SHP, the ship speed does increase with the bubbler system 'ON'. It should, however, be noted that the ice thickness for the measurements with bubbler 'ON' and 'OFF' was not the same. Measurements in 33.2 cm thick ice, on the other hand, show that the bubbler system does not have any effect on ship speed for speeds greater than 2.5 knots (Figure 3.7). It is, however, possible that the bubbler system is effective below this speed.
2. Accurate measurements of the turning circle of the M.V. Arctic have been obtained in sheet ice from 19.5 cm to 35.5 cm thick. The results of measurements in 33 cm thick ice and at SHP = 1500 (metric) maximum show that:
 - 2.1 The turning circle diameter in sheet ice was 1.7 nautical miles at full power and 1.25 nautical miles at half power.
 - 2.2 Using the bubbler system reduced the turning circle diameter to 1.42 nautical miles at full power, and to 0.55 nautical miles at half power.
3. Vibration of the hull in a vertical mode at 0.9 Hz was detected by the accelerometers and mid-section strain gauges of the data acquisition system. The strains and accelerations are consistent with the 2-node vertical mode of hull vibration.
4. Hull strains recorded during passage through 30 cm thick ice were not significant (i.e. greater than $30 \mu S$) even at speeds of 6.2 m/sec (12 knots).
5. The expected mode of ice failure is by flexural near the bow and by compression at the shoulder. Since the compressive strength of ice is much higher than the flexural strength, one would expect higher strain readings from strain gauges at the shoulder than those at the bow. The recorded strains show that:

- (i) For the first year ice, the ice fails by flexural near the bow and by compression at the shoulders.
 - (ii) For the multi-year ice, the strains recorded at the bow are of the same magnitude as those recorded at the shoulder indicating that the ice failure was by compression along the waterline as far as the strain gauge extends on the shoulder.
6. Multi-year ice impacts show an expected inverse relationship between the number and magnitude of impacts.
 7. In the ice conditions encountered in 1980 the strain gauges attached to plates generally indicated higher strain values than the frame strain gauges. Strain gauges attached to plates recorded faster strain variations than those attached to frames; the associated rise times for plates and frames were about 0.07 seconds and 0.12 seconds respectively. The recorded impact strains lasted 0.15 - 0.30 seconds.
 7. A few ice impacts have been analysed by studying particular strain gauge patterns. The aim of this exercise was to demonstrate that there is a sound analytical method which forms the basis for future software development. The strain gauge patterns indicated that ice impacts occur as very localized single loads. The load distribution is largely controlled by the compressive ice strength.
 8. One of the largest strains recorded during the 1980 season was 1540 μ S resulting from an impact causing plastic deformation in the outer skin. A visual inspection of the bow indicating a dent confirmed the above record. The impact load had been estimated as 850 tons.
 9. Much useful data has been recorded on tape for later computer analysis.

5. RECOMMENDATIONS

1. Further dedicated trials should be performed to measure the performance of the ship in different ice conditions.
2. A total of 31 strain gauges (21 frame gauges and 10 plate gauges) between frames 178 and 202 have failed and should be replaced prior to the commencement of the next data collection season. In line with conclusion 4, it is recommended that the strain gauge array be extended back onto the shoulders of the bow.

We strongly recommend to have these gauges installed prior to starting the 1981 data collection season.

3. The maximum impact duration of 0.3 seconds which had been established at the beginning of the season represents an important finding with respect to the choice of sampling patterns. With a sampling rate of one sample per second in the peak holding mode almost all impacts can be properly recorded without encountering a possible superposition of two or more impacts at a particular gauge. A sampling rate of one sample/second is recommended during the normal operating period.
4. The filters used on the accelerometers have a corner frequency of 1.2 Hz. With the identification of a hull flexing mode with a frequency of 4.6 Hz it is recommended that a 12 Hz filter (already available) be used with the accelerometers. The filter output should then be sampled at 50 samples/sec.
5. More knowledge is needed to better establish the relationship between strains and ice loads. This can be done either by conducting more calibration tests (costly) or by doing an analytical study which involves a systematic investigation of various load cases.